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An Urban Autonomic Traffic Energy Decision Model Based on Human Micro Behaviors Research

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Abstract – Along with rapid economic growth, urban traffic has become a complicated worldwide issue, which synthesizes out-of-order jam, energy consumption and GHG (Greenhouse Gas) emission. An autonomic traffic and energy model is proposed based on the micro behavior simulation, in which an information decision factor is introduced. Thus the method of transportation and alternative routes for avoiding traffic have been controlled and optimized dynamically. Simulation with NetLogo verifies that the model can perform efficiently for the optimization among traffic, energy and greenhouse gas emission and some practical use for solving existing traffic problems.

Index Terms - micro-behavior; autonomic traffic and energy model; information decision; ABM; NetLogo simulation; High Performance Computing

I Introduction

Our current transportation system's goal is to send passenger-cargo from one location to the next. Along with Rapidly Developing Economies, global data demonstrate that passenger-cargo traffic mileage and energy consumption is directly related to the changes of the GDP. So the finiteness of urban land resources and transportation load demand increases make the modern transportation system have to confront with not only an out-of-order problem but also a mixed worldwide problem in which transport planning, traffic tools industry, energy support safety, environmental pollution and greenhouse gas emission are involved.

The present-day traffic plan model, which is based on the average property within a traffic community, has four sections, trip generation, trip distribution, trip mode selection, and traffic operation. Because of the obvious mix of these characteristics, it is difficult in balancing the traffic demands and service level; therefore, many scholars have taken much research on it.¹

On trip mode selection, the opportunity model, growth factor model, gravity mode and information entropy model etc. were mainly intervened^[1-4]. In road selection mode, the traffic entropy model, ecological footprints theory, dynamic traffic assignment theory and transport derivation and dynamic navigation model etc. was used^[5-7]. On traffic energy consumption and emission, an ASIF(Activity x modal Share x energy Intensity x carbon intensity of Fuel = GHG) model proposed by IEA (International Energy Agency)was used, which works with traffic level, traffic structure and energy consumption intensity. On emission, a Greet model of WTW(Well To Wheel) and a whole lifecycle evaluation methodology of IEA were put forward, in which the whole processes from fuel exploring, refining, distributing, fuel station operation to the use of terminal vehicles were considered. However, these methods must be working on the exact estimate of the above problems. Otherwise no reliable results can be reached. Some scholars also consider that traffic system is a complex, open and huge system, and traffic problem is nonlinear, dynamic, time-variant. A different individual's decision may result in very different results, confusing the system, so decision-making is obscure. Moreover the urban traffic system is extremely complex on both structure and function, especially on behavior and evolution. Then a complexity method is proposed based on ABM (Agent Based Modeling)^[8-11]. Because of the difficulties in behavior sampling, the behavior decision probability is highly dependent on the mass data and high requirement for modeling, this method has limitations to practical application.

Though good solutions to traffic problems were put forward in the above models and methods in various professional fields, the solution to unhook the traffic system from activity amount, energy consumption and exhaust emission with GDP, to

synthetically solve the trip model mixed urban public traffic with the private vehicles, and to break the close relationship between economy and traffic problem, is still an insoluble dilemma. An autonomic traffic model proposed in this paper, by the introduction of decision-making factor, has reached optimized results with in order, energy consumption and greenhouse gas emission in traffic fields.

II Urban Traffic Autonomic Model

The core concept of the urban traffic autonomic model is research on the micro behavior, with high quality and great sustainable traffic theory in order to detach it from the GDP growth and lower resource consumption while increasing eco-friendliness.

In the model [Fig. 1] shows focuses around trip strategy, which revolves around traffic information decision center and the traffic supply dispatch decision. The multiple isomorphism interaction among traveler individuals, which based on the information decision factors influence, will provide power for the system evolvement. Different from the aggregation and non-aggregation models which are used in traffic frequently, the model's dynamic base lies in the interaction guided by enough effective information. According to the trip demand, guided by the traffic policy and based on the dynamic road situation, decision center provides a set of trip mode solutions such as trip tactics, trip time, traffic tools, trip fees, trip energy usage and greenhouse gas emission, bus

station BBS (Bulletin Board System), SMS (Short Message Service) and other services on smart phones. The traveler will freely enjoy the updated information such as live traffic, trip experience, social assessment, and traffic tools on every trip time point. Meanwhile a continuous, repeated and multiple decision environments can help the traveler make the decision according to his own requirements. So, the traveler can make the trip decision on the transparent condition of dynamic information feedback, on the interactions of time, price, energy usage and other crucial communal factors.

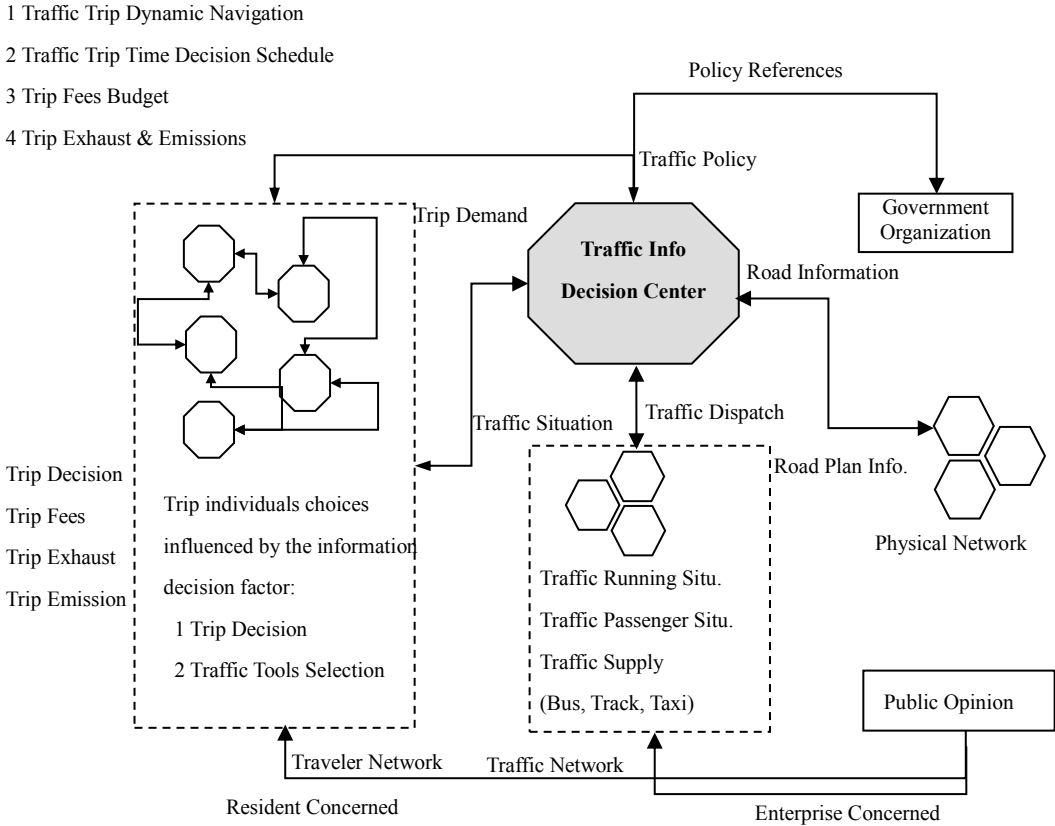


Fig. 1 Structure of Urban Traffic Autonomic Model

II Basic Functions of Urban Traffic Autonomic Model

Requirement-driven is the behavior decision basis for the travelers. The decision includes trip destination, time and mode.

First the subject assumes trip expectations, among the possible trip combinations, considering of trip fees, comfort level, social effects and other elements that may influence the subject behavior. The information decision factor may help the subject select a satisfying trip plan, then the decision process exits. Based on the information decision factor, the trip fee, subjective evaluation and social assessment of trip possibilities that subject tests on the trip mode have made up of the three main elements which helps the subject to make the trip decision.

Assuming that subject i has k kinds of trip plans at t moment and No. n time trip, then No. j trip mode is:

$$TP_{i,t}^{n,j} = TE_{i,t}^{n,j} \left\{ TD_{i,t}^{n,j}, TS_{i,t}^{n,j}, TM_{i,t}^{n,j} \right\} \quad (1)$$

$TE_{i,t}^{n,j}$: The accessible trip information

$TD_{i,t}^{n,j}$: Trip destination

$TS_{i,t}^{n,j}$: Start time $TM_{i,t}^{n,j}$: trip mode

Therefore, assuming that trip distance is $\hat{d}_{i,t}^{n,j}$ on the No. j kind of trip plan, trip time is $\hat{t}_{i,t}^{n,j}$, trip information is $\hat{e}_{i,t}^{n,j}$, direct cost is $\hat{c}_{i,t}^{n,j}$, comfort level is $\hat{f}_{i,t}^{n,j}$, other subject experience is $\hat{h}_{i,t}^{n,j}$, attitude evaluation is $\hat{a}_{i,t}^{n,j}$, social assessment is $\hat{s}_{i,t}^{n,j}$, destination profit is $\hat{v}_{i,t}^{n,j}$, and trip distribution is $p_i^{n,j}$. Among them, trip distance, time and direct cost all are the function of source, and the destination, comfort level/subject experience can be reached according to the individual's trip history records. The destination profit shows that trip mode may bring the choice priority, trip information, as the crucial elements, embodies the service level in urban traffic.

Assuming on moment t , the duration that individual i will use the private car is tu , life cycle of the car is tl , value when purchased is v , trip information is e , trip abrasion is $w_{i,t}^e$, fuel cost is $f_{i,t}^e$, toll charge is $g_{i,t}^e$, parking fee is $r_{i,t}^e$, then the direct cost estimation of a private car $\hat{c}_{i,t}$ may be demonstrated as :

$$\hat{c}_{i,t}^e = w_{i,t}^e + f_{i,t}^e + g_{i,t}^e + r_{i,t}^e + fs_i^e(v, tu/tl) - fr_i^e(v, tu/tl) \quad (2)$$

$fs(\cdot)$: Cost diluted function, $fr(\cdot)$: value recycled function, they are both decreasing functions. Cost diluted will be counted into cost again, as salvage value is a positive profit.

In a similar way, by m times traffic combinations, $ti_{i,t}^e$ is a certain time combination ticket price, the trip information e provides optimization plan, then the public transit trip cost can be expressed by

$$\hat{c}_{i,t}^e = \sum_{k=1}^m k \square_{i,t} \quad (3)$$

Individual attitude evaluation may be determined by the trip information got from the initial value. Its concrete value shows that individual's integral predilection or rely on the different trip mode. Social assessment will be achieved by the weight on the attitude and behavior of the reference group member. Member's weight is decided by individual relative social status or social tendency. It is expressed as:

$$\begin{aligned} \hat{s}_{i,t}^{n,j} &= \omega_{A,i,t} \cdot \tilde{L}_{g,i,t}^{i,j} + \omega_{B,i,t} \cdot \tilde{L}_{g,i,t}^{i,j} \\ &= 1 / \left(\sum_{ii=1}^N d_{ii} \cdot f_{pi}(p_{ii,t} - p_{i,t}) \right) \sum_{ii=1}^N (\omega_{A,i,t} \cdot A_{ii,t}(TM_{i,t}^{n,j}) + \omega_{B,i,t} \cdot B_{ii,t}(TM_{i,t}^{n,j})) \cdot d_{ii,t} \cdot f_{pi}(p_{ii,t} - p_{i,t}) \end{aligned} \quad (4)$$

d_{ii} : The close and distant distance from individual i to the No. ii referential group member

$f_{pi}(p_{ii,t} - p_{i,t})$: Social status D-value interactive function

$A_{ii,t}(TM_{i,t}^{n,j})$, $B_{ii,t}(TM_{i,t}^{n,j})$: No ii referential member's attitude and behavior to trip mode $TM_{i,t}^{n,j}$ respectively

Assuming that incoming level is $ic_{i,t}^n$ for individual i at moment t , then individual evaluation normalizing value on the No. n time trip, No. j kind trip plan is:

$$P_{i,t}^{n,j} = \Omega(\hat{t}_{i,t}^{n,j}, \hat{f}_{i,t}^{n,j}, \hat{h}_{i,t}^{n,j}, \hat{a}_{i,t}^{n,j}, \hat{v}_{i,t}^{n,j}, ic_{i,t}^n) \quad (5)$$

The individual's trip distribution is an uncertain problem, as it includes the trip distance frequency distribution. According to the Entropy Maximized distribution function, the trip distribution probability is:

$$p_{i,t}^{n,j} = \exp(-\lambda - \sum_{k=1}^n \lambda_k \hat{d}_{i,t}^{n,j}) \quad (6)$$

In the process of trip mode decision, the corresponding energy exhaust and emission may be expressed as:

$$\begin{aligned} PE_{cm,i,j} &= \sum_k PF_{i,j,k} \times PC_{j,k} \\ PC_{j,k} &= PC \times e_{j,\dots} \sim_{j,\dots} \\ CO_{2,j,k} &= \{CP_j \times \phi_j - (VOC_{j,k} \times \alpha_j + CO_{j,k} \times \beta_j + CH_{4,j,k} \times \delta_j) / \phi_j\} \end{aligned} \quad (7)$$

$PE_{cm,i,j}$: Total quantity of greenhouse gas i emission in No. j process

$\sum_k PF_{i,j,k}$: factor of greenhouse gas i driven by j kind of energy on transport tool k

$PC_{j,k}$: Traffic energy quantity under j kind exhaust on transport tool k .

PC : Total energy exhaust

$e_{j,\dots}$: Proportion of energy j in total energy exhaust

$e_{j,\dots}$: Proportion of transport tool k used energy j

$CO_{2,j,k}$: CO2 emission factor transport tool k driven by j kind energy

CP_j : C potential emission coefficient of j kind energy exhaust

ϕ_j : Ratio of oxidation of coal j kind fuel burning

$VOC_{j,k}$: VOC emission coefficient produced by transport toll k driven by fuel j

α_j : Carbon content, corresponding $CO_{j,k}$ is CO emission factor, $CH_{4,j,k}$ is CH4 emission factor, ϕ_j is CO2 transfer coefficient

Individual time value, comfort level value can be obtained by a survey. Combined with energy exhaust and emission, the environment value normalization function is assumed as:

$$\text{Social assessment: } S_{i,t}^{n,j} = \lambda_{i,t}^{n,j} \cdot \bar{S}_{i,t}^{n,j} \cdot \bar{S}_{cm,i,j}$$

$$\text{Cost \& fee: } C_{i,t}^{n,j} = \omega_{i,t}^{n,j} \cdot \bar{C}_{i,t}^{n,j} \cdot PE_{cm,i,j}$$

According to Prospect Theory, the absolute value of relative profit, individuals care more about the D-value of the reference. Assuming that individual i , moment t , No. n time trip, the assessment expectation is $\bar{P}_{i,t}^n$, social assessment expectation is $\bar{S}_{i,t}^n$, cost & fee expectation is $\bar{C}_{i,t}^n$, then No. j trip plan, the integrative assessment value is:

$$TV_{i,t}^{n,j} = \Re((P_{i,t}^{n,j} - \bar{P}_{i,t}^n), (S_{i,t}^{n,j} - \bar{S}_{i,t}^n), (C_{i,t}^{n,j} - \bar{C}_{i,t}^n), \omega_i^p, \omega_i^s, \omega_i^c) \quad (8)$$

$\omega_i^p, \omega_i^s, \omega_i^c$ is individual i distributes weight respectively to individual evaluation, social assessment and cost & fee.

Under the simplest circumstances, the function $\Re(\cdot)$ may be linear forming. That is:

$$TV_{i,t}^{n,j} = \omega_i^p \cdot pV(P_{i,t}^{n,j} - \bar{P}_{i,t}^n) + \omega_i^s \cdot pV(S_{i,t}^{n,j} - \bar{S}_{i,t}^n) + \omega_i^c \cdot pV(C_{i,t}^{n,j} - \bar{C}_{i,t}^n) \quad (9)$$

$pv(\cdot)$: Cost Function, reference to S Form origin concave function in Prospect Theory.

According to Bounded Rationality Assumption, the decision maker looks for a satisfactory solution, not an optimum solution. When effectiveness assessment of a proposal is higher than the preset standard, a satisfactory solution is found, the decision making process ends. Assuming that individual i , moment t , n time trip, the general trip satisfactory degree is $SAT_{i,t}^n$, which is usually assumed to be relative stable after adaptive phase.

Assuming that in the No. j kind trip plan, the optional parameters are $X_{i,t}^{n,j} \in \{0,1\}$. From the first plan, if $TV_{i,t}^{n,j} \geq SAT_{i,t}^n$, then $X_{i,t}^{n,j} = 1$, the individual has found the satisfactory solution j , decision process is over, otherwise keep attempt the No. $j+1$ trip plan.

If the all plans can't satisfied with the above conditions, then the individual I will look up an optimum solution among the k kinds of plans. That is to solve the following equations:

$$\begin{aligned} \text{Max } & \sum_{j=1}^k X_{i,t}^{n,j} \cdot TV_{i,t}^{n,j} \\ & \sum_{j=1}^k X_{i,t}^{n,j} = 1, X_{i,t}^{n,j} \in \{0,1\} \end{aligned} \quad (10)$$

IV Simulation of the Urban Traffic Autonomic Model

Simulation of UTAM is a multiple agent simulation mode in an urban traffic system which develops from bottom to upper based on a micro subject decision. It adopts NetLogo platform and JAVA2 framework. A whole new UTAM ABM parallel Repast platform simulation model is being developed on HPC (High Performance Computation). During the simulation process system is initialized first, then every agent goes along the Time axis in parallel and continues to interact until it achieves the predetermined time step, then the process ends. (Shown below in Fig. 2)

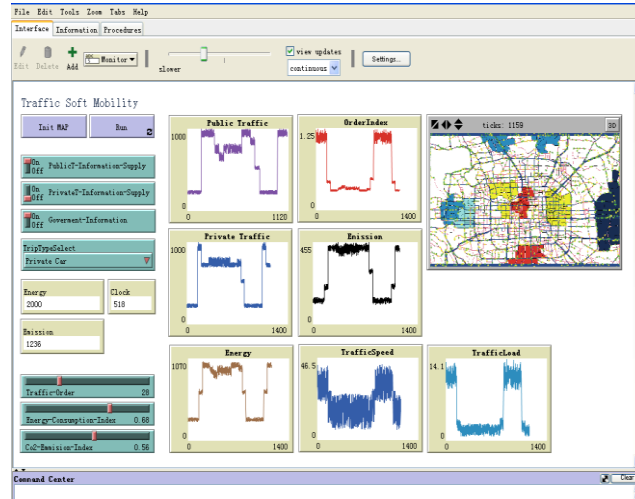


Fig. 2 Interface of simulation on the UTAM with NetLogo

Initial setting is to assign every AGENT an initial state in the model and give a corresponding value to the surroundings. In this procedure, first a virtual city, which includes traffic nodes, road and every land shape distribution, is required to be established either by importing from a real city's GIS information or by generating automatically according to the coordinate file. Then the required amount, each family's characters with every member's age, income, career and etc. in accordance with the

probability distribution are generated. The probability distribution can be received by many means, especially questionnaire surveys. Later it distribute families to a residential district of the virtual city according to the statistical nature while designating the prime trip goal such as job or study and other destination choices. When residential or job is assigned, it sets up the referent group on the basis of families social character, then assign values to trip character of every family member. After a virtual city is generated, the system sets up the road traffic system, including road permits and traffic capacity. The traffic information decision center in the system provides information decision and suggestions to all agents. The system simulates the agent decision. For example, after setting the system public traffic service sections or service style, then the public traffic running agent can be established and confirm the running route, service level and so on. In addition, the media, all the policies and timetable are still to be designated in the initial set.

After the initialization, the program starts to simulate the core of which is to interact among the agent's parallel. Every agent interacts with the relative ones in the time step according to the given rules, and update their behavior status such as if the habitants replace traffic tools, trip destination or mode selection, if the public transport company regulate the bus network, it can determine the traffic service levels and so on. The simulation loops continuously until the preset time step is reached.

Simulation results show when information decision factors are used, the whole trip mode tends to be in order, and the probability that private car owners select the public traffic increases obviously. The Green curve shows the trip probability of private cars, while the red curve shows that of the public traffic. Simulation results show private car method probability of high dependence on private car owners is about 90.2% and public transportation method probability of low dependence on private car owners is only about 70% without information decision support. However, both travel patterns are about 84.7% with information decision support. High dependence on private car owners reduce private car usage rate from 90.2% to 84.7%. Low dependence on private car owners also increases public transportation usage rate from 70% to 83%. Information decision factor reflects the effect of better travel behaviors (Fig.3).

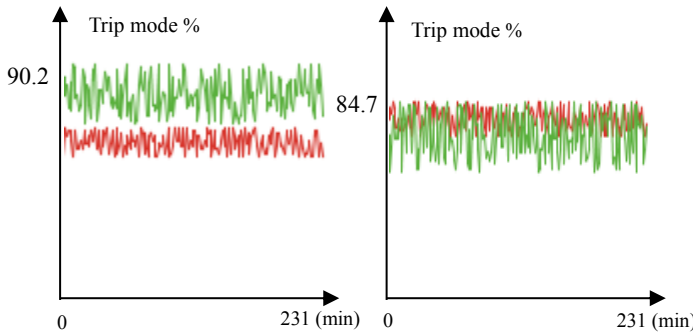


Fig. 3 Private car owner trip mode changes when information decision factor introduced

Since information decision is introduced in the transportation system, traffic average load falls down, while the average speed increase, energy exhaust and emission drops down remarkably (Fig. 4). The road block rate drops down from 14.1 to 7% of traffic peak time.

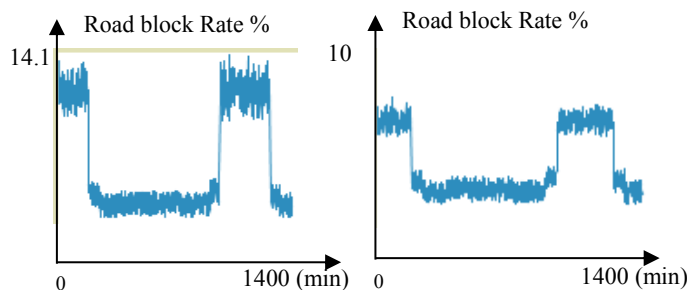


Fig. 4 Road block rate comparison when information decision factor introduced

And, the city traffic energy Index also drops down from 1080 to 962, reflects about 20% energy conservation effect (Fig. 5).

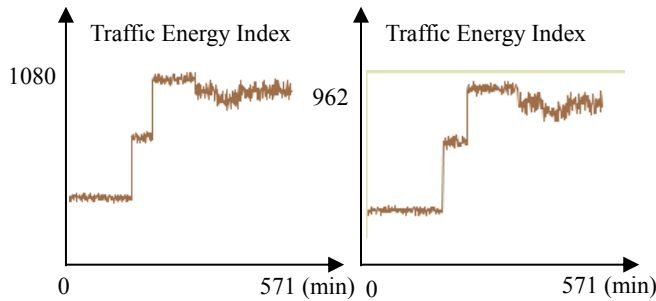


Fig. 5 Traffic Energy consumption index comparison when information decision factor introduced

V Conclusion

By constructing the autonomic model based on the micro behavior information decision and simulation, reasonable information can result in a significant influence on the traveler trip mode. Public traffic and private trip mix mode can be dominated by traffic information decision center and breaks existing traffic network limits without road system retrofit. The autonomic traffic and energy model presented in the paper shows that information decision plays a very important role in the behavior interactions from the simulation result. The individual's budget restrictions, public and private transportation marginal costs, market regulations and other factors can work together. Micro characteristics of the traveler's mode selected can combine with macro performance of the urban traffic system. Therefore the urban traffic autonomic model, centered on the information decision factor, introduced the micro subject interactions, provides a powerful research platform for the urban traffic plan, structure regulation, energy exhaust and emission, traffic information services and the implementing efficacy estimation. At the next step, a huge ABM system simulation based on parallel Repast platform on high performance computer and a new dynamic optimization traffic message service application on smart phones will be developed.

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